QUANTUM-CORRELATED MEASUREMENTS RELATED TO THE DETERMINATION OF γ/ϕ_3

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Abstract

Measurements of D^0 meson strong-phase parameters in quantum-correlated $\psi(3770) \to D^0\overline{D^0}$ decays by the CLEO collaboration are presented. These measurements play an important role in the determination of the unitarity triangle angle γ/ϕ_3 from B-meson decays. Measurements of the strong-phase parameters for $D^0 \to K^0\pi^+\pi^-$, $D^0 \to K^0K^+K^-$, $D^0 \to K^-\pi^+\pi^0$, and $D^0 \to K^-\pi^+\pi^+\pi^-$ decays are described along with their impact on the determination of γ/ϕ_3.

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I. INTRODUCTION

One of the primary goals of flavor physics is to determine the angle γ/ϕ_3 of the $b-d$ CKM triangle [1]. Aside from being the least well known angle of the unitarity triangle (UT), it can be determined in tree-level processes that have negligible contributions from beyond the standard model physics, unlike most other constraints on the UT [2]. Therefore, any disagreement between the tree-level measurement of γ/ϕ_3 with predictions derived from other measurements is a signature of new physics.

The most promising decay to determine γ/ϕ_3 at tree level is $B^- \to \widetilde{D}^0 K^-$ where $\widetilde{D}^0$ is a D^0 or $\overline{D^0}$ decaying to the same final state [3].[1] The sensitivity to γ/ϕ_3 arises from the interference between the decay $B^- \to D^0 K^-$ and the color and CKM-suppressed decay $B^- \to \overline{D^0} K^-$. The most precise measurements [4, 5] of γ/ϕ_3 come from decays where $\widetilde{D}^0 \to K^0_S h^+ h^-$ [6, 7]. Here, h is π or K. Other promising $\widetilde{D}^0$ final states are $K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$ [8, 9]. All these measurements depend on parameters related to the decay of the D^0 meson. Knowledge of the D-decay parameters *a priori* can greatly improve the determination of γ/ϕ_3. These proceedings summarise the measurements [10, 11] of these parameters made by the CLEO collaboration and estimates their impact on the determination of γ/ϕ_3.

II. MEASUREMENT OF THE STRONG-PHASE PARAMETERS OF $D^0 \to K^0 h^+ h^-$ DECAYS

The sensitivity to γ/ϕ_3 in $B^- \to \widetilde{D}^0 (K^0_S h^+ h^-) K^-$ comes from studying differences between the $\widetilde{D}^0 \to K^0_S h^+ h^-$ Dalitz plot for both B^- and B^+ decays. Current measurements of γ/ϕ_3 require a model of the $\widetilde{D}^0 \to K^0_S h^+ h^-$ Dalitz plot, which is derived from flavor-tagged samples of $D^0 \to K^0_S h^+ h^-$. The assumptions used to determine the model introduce a systematic uncertainty on γ/ϕ_3 which is estimated to be between 3° and 9° [4, 5]. This is significantly less than the current statistical uncertainty but it will be a limiting factor in future measurements [12, 13]. Therefore, it is desirable to perform the measurement in a model-independent manner. Such a method was proposed in Ref. [6] and has been developed significantly by Bondar and Poluektov [14]. The method requires determining yields in bins of the $\widetilde{D}^0 \to K^0_S h^+ h^-$ Dalitz plot for B^- and B^+ decay, which depend on the B-decay parameters and two new parameters c_i and s_i, which are the amplitude-weighted averages over the bin of the cosine and sine of the difference in strong-phase difference, $\Delta\delta_D$, between Dalitz-plot points (m^2_-, m^2_+) and (m^2_+, m^2_-). Here $m_\pm$ is the invariant-mass of the $K^0_S h^\pm$ pair. It can be shown [10, 14] that between 80% to 90% of the statistical sensitivity to γ/ϕ_3 of the unbinned method can be obtained by choosing bins corresponding to equal intervals of $\Delta\delta_D$ according to an amplitude model. An example of such a binning is shown in Fig. 1.

The values of c_i and s_i can be measured in quantum-correlated $D^0\overline{D^0}$ decays of the $\psi(3770)$. The $D^0\overline{D^0}$ are produced in a $C=-1$ state. Therefore, if one D meson decays to a CP-eigenstate the other D-meson is in the opposite CP-eigenstate. The difference between CP-even and CP-odd tagged Dalitz plots in each bin is related to the c_i parameters. In addition, the Dalitz plot of quantum-correlated events where both D-mesons decay to $K^0_S h^+ h^-$ is sensitive to both c_i and s_i. The strong-phase parameters for the decay $D^0 \to$

[1] Here and throughout this paper the charge-conjugate state is implied unless otherwise stated.

$K^0_L h^+h^-$ (c'_i and s'_i) are closely related to c_i and s_i such that using decays of the type $K^0_S h^+h^-$ *vs.* $K^0_L h^+h^-$ greatly improve the precision on c_i and s_i.

The CLEO-c experiment [15] collected $e^+e^- \to \psi(3770) \to D\bar{D}$ data corresponding to an integrated luminosity of 818 pb^{-1}. The fact that all particles arise from D-meson decay in the final state leads to both D mesons being reconstructed exclusively with high efficiency and purity. For $D^0 \to K^0\pi^+\pi^-$ ($D^0 \to K^0K^+K^-$) decay the numbers of CP-tagged and $K^0h^+h^-$ *vs.* $K^0h^+h^-$ candidates selected are 1661 and 1674 (219 and 335), respectively.

A maximum-likelihood fit is performed to the bin yields of the CP-tagged and $K^0h^+h^-$ *vs.* $K^0h^+h^-$ events to extract $c_i^{(\prime)}$ and $s_i^{(\prime)}$. The results are presented in detail elsewhere [10]. The values of $c_i^{(\prime)}$ and $s_i^{(\prime)}$ are determined for several binning variations for both $D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to K^0_S K^+K^-$. These binnings allow flexibility given different scenarios for the amount of B data and the background environment. The measured values of c_i and s_i are found to be in reasonable agreement with the values predicted by the amplitude models presented in Refs. [4, 16]. The largest systematic uncertainties arise from the modelling of the background. However, none of these measurements are systematically limited.

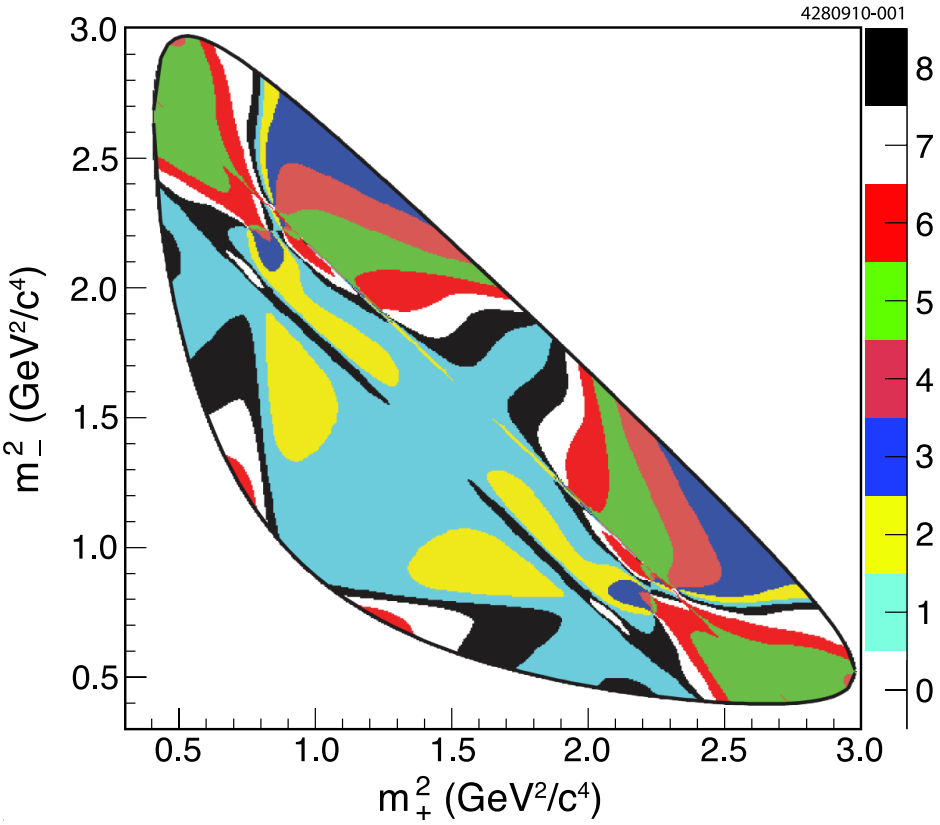

FIG. 1: Dalitz-plot binning for $D^0 \to K^0_S\pi^+\pi^-$ in region of similar $\Delta\delta_D$.

III. MEASUREMENT OF THE COHERENCE FACTOR AND STRONG PHASE DIFFERENCES IN $D^0 \to K^-\pi^+\pi^0$ AND $D^0 \to K^-\pi^+\pi^+\pi^-$

The rate of decays $B^- \to \widetilde{D}^0(K^+\pi^-)K^-$ is particularly sensitive to γ/ϕ_3 because the two interfering amplitudes are of similar size due to the doubly-Cabibbo suppressed (DCS) D^0 decay coming from the favored B^- amplitude [8]. The rate depends not only on γ/ϕ_3 but on the strong-phase difference between the Cabibbo-favored and DCS $\widetilde{D}^0 \to K^+\pi^-$ decays. The measurement of this parameter by the CLEO collaboration is described elsewhere in these proceedings [18].

Via the same mechanism there is potential sensitivity to γ/ϕ_3 from $B^- \to \widetilde{D}^0 K^-$, where $\widetilde{D}^0 \to K^+\pi^-\pi^0$ or $\widetilde{D}^0 \to K^+\pi^-\pi^-\pi^+$ [9]. These modes have significantly larger branching fractions than $\widetilde{D}^0 \to K^+\pi^-$ [17]. However, the dynamics are more complicated because there is variation of the strong-phase difference over the multi-body phase-space. This leads to the introduction of a new parameter referred to as the coherence factor R_F ($F = K\pi\pi^0$ or $K3\pi$), which multiplies the interference term sensitive to γ/ϕ_3. The value of R_F can vary between zero and one. If there is only a single intermediate resonance or a few non-interfering resonances the coherence factor will be close to one and the decay will behave just like $\widetilde{D}^0 \to K^+\pi^-$. If there are many overlapping intermediate resonances the coherence factor will tend toward zero, limiting the sensitivity to γ/ϕ_3. However, even if there is limited sensitivity to the phases when $R \sim 0$ there is enhanced sensitivity to the magnitude of the amplitude ratio between the $B^- \to D^0K^-$ and $B^- \to \overline{D^0}K^-$ decays; improved knowledge of this parameter will then lead to better overall sensitivity to γ/ϕ_3 in a global fit to all $B^- \to \widetilde{D}^0 K^-$ decays.

The values of R_F and the average-strong phase difference δ_D^F have been measured by CLEO-c [11]. Sensitivity comes from the quantum-correlated $D^0\overline{D^0}$ events with F tagged by either CP-eigenstates or $K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$, where the tag kaon charge is the same as the signal. A χ^2 fit to the yields gives: $R_{K\pi\pi^0} = 0.84 \pm 0.07$, $\delta_D^{K\pi\pi^0} = (227^{+14}_{-17})^\circ$, $R_{K3\pi} = 0.33^{+0.26}_{-0.23}$, and $\delta_D^{K3\pi} = (114^{+26}_{-23})^\circ$. Figure 2 shows the 1σ, 2σ, and 3σ regions of $(R_{K\pi\pi^0}, \delta_D^{K\pi\pi^0})$ parameter space; the coherence of $D^0 \to K^-\pi^+\pi^0$ is clearly observed. The impact of these results on the measurements of γ/ϕ_3 is discussed in the following section.

IV. IMPACT OF RESULTS ON THE MEASUREMENT OF γ/ϕ_3

The determination of the c_i and s_i in quantum-correlated D-decay allows the measurement of γ/ϕ_3 without a model induced systematic uncertainty. However, this is replaced by uncertainty due to the limited statistics used to measure c_i and s_i at CLEO-c. This uncertainty is estimated to be between 1.7° and 3.9° (3.2° and 3.9°) depending on the binning of the $D^0 \to K^0_S\pi^+\pi^+$ ($D^0 \to K^0_S K^+K^-$) Dalitz plot. The systematic uncertainty on γ/ϕ_3 can be reduced by about a factor of three if BES-III collects 10 fb^{-1} of integrated luminosity at the $\psi(3770)$ resonance [19]. This would reduce the uncertainty to the order of 1°, which would not only be adequate for LHCb but also for future higher luminosity facilities [13, 20].

The impact of the measurements of R_F and δ_D^F at LHCb is evaluated using the yield estimates for $B^- \to \widetilde{D}^0(K^\pm\pi^\mp)K^-$ and $B^- \to \widetilde{D}^0(K^\pm\pi^\mp\pi^+\pi^-)K^-$ decays in a dataset corresponding to 2 fb^{-1} of integrated luminosity at a center-of-mass energy of 14 TeV [21]. In addition, the yield of $B^- \to \widetilde{D}^0(K^\pm\pi^\mp\pi^0)$ is assumed to be half that of $B^- \to \widetilde{D}^0(K^\pm\pi^\mp\pi^+\pi^-)K^-$ with the same level of background reflecting the difficulties

associated with π^0 reconstruction in the hadronic environment. The sensitivity to γ/ϕ_3 from LHCb data alone is 9.7°. Including the CLEO-c constraints on R_F and δ_D^F this improves to 7.5°. The introduction of the CLEO-c constraints is equivalent to 70% more LHCb data. This clearly illustrates the power of quantum-correlated measurements in aiding the determination of γ/ϕ_3. BES-III data could lead to at least a further 10% reduction of the uncertainty on γ/ϕ_3.

In conclusion, the first quantum-correlated measurements of strong-phase parameters of D-decay at CLEO-c have been presented and their positive impact on the determination of γ/ϕ_3 at LHCb has been illustrated. Further improvements are possible by exploiting the larger sample of quantum-correlated decays that will be available at BES-III. Furthermore, there are other $\widetilde{D}^0$ decay modes of interest to the measurement of γ/ϕ_3 for which the strong-phase parameters have yet to be determined: $K^0_S\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0$, $K^0_S K^\pm\pi^\mp$, and $K^+K^-\pi^+\pi^-$.

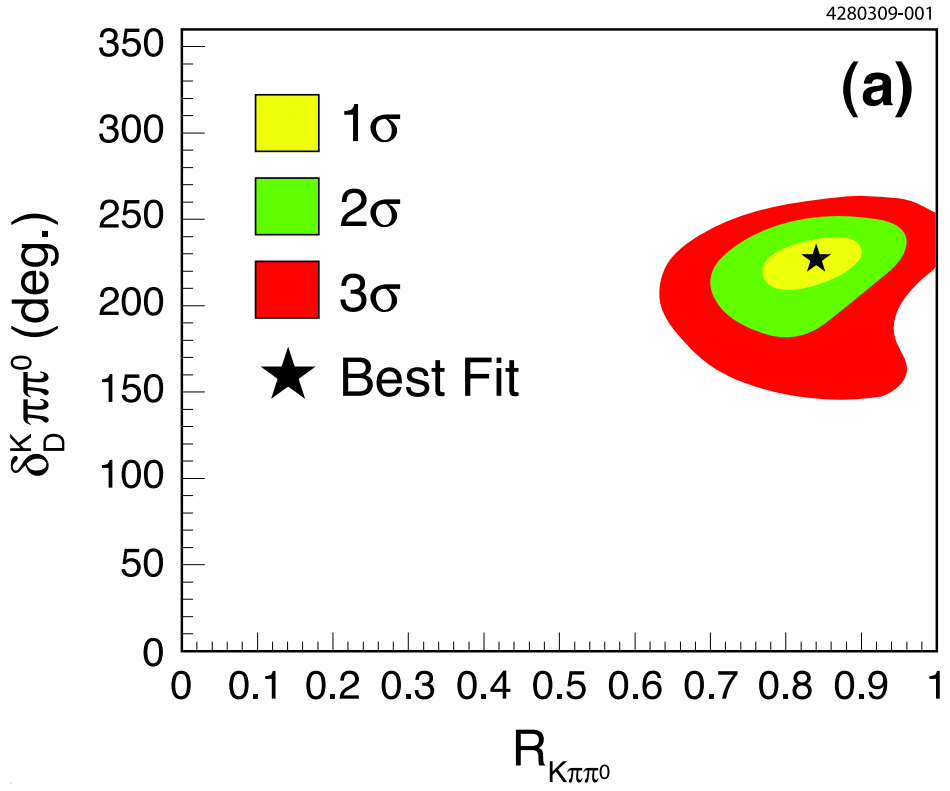

FIG. 2: The 1σ, 2σ, and 3σ allowed regions of ($R_{K\pi\pi^0}$,$\delta_D^{K\pi\pi^0}$) parameter space.

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[1] N. Cabibbo, *Phys. Rev. Lett.* **10**, 531 (1963); M. Kobayashi and T. Maskawa, *Prog. Theor. Phys.* **49**, 652 (1973).
[2] CKMfitter Group, (A. Höcker *et al.*), *Eur. Phys. J. C* **21**, 225 (2001); CKMfitter Group (J. Charles *et al.*), *Eur. Phys. J. C.* **41**, 1 (2005), and updates at http://ckmfitter.in2p3.fr/; M. Ciuchini *et al.*, *J. High Energy Phys.* 0107 (2001) 013; UTFit Collaboration (M. Bona *et al.*), *J. High Energy Phys.* 081 (2006) 10, and updates at http://www.utfit.org/.
[3] M. Gronau and D. Wyler, *Phys. Lett. B* **265**, 172 (1991); M. Gronau and D. London, *Phys. Lett. B* **253**, 483 (1991).
[4] Belle Collaboration (A. Poluektov *et al.*), *Phys. Rev. D* **81**, 112002 (2010).
[5] *BABAR* Collaboration, (P. del Amo Sanchez *et al.*), *Phys. Rev. Lett.* **105**, 121801 (2010).
[6] A. Giri, Y. Grossman, A. Soffer, and J. Zupan, *Phys. Rev. D* **68**, 054018 (2003).
[7] A. Bondar, *Proceedings of BINP Special Analysis Meeting on Dalitz Analysis*, 24-26 Sep. 2002, unpublished.
[8] D. Atwood, I. Dunietz, and A. Soni, *Phys. Rev. Lett.* **78**, 3257 (1997); D. Atwood, I. Dunietz, and A. Soni, *Phys. Rev. D* **63**, 036005 (2001).
[9] D. Atwood and A. Soni, *Phys. Rev. D* **68**, 033003 (2003).
[10] CLEO Collaboration (J. Libby *et al.*), arXiv:1010.2817 [hep-ex], accepted by Phys. Rev. D.
[11] CLEO Collaboration (N. Lowrey *et al.*), *Phys. Rev. D* **80**, 031105 (2009).
[12] J. Libby, CERN-LHCb-2007-141; V. Gibson, C. Lazzeroni, and Y.-Y. Li, CERN-LHCb-2008-028.
[13] T. Aushev *et al.*, KEK-Report 2009-12; M. Bona *et al.*, SLAC-R-856.
[14] A. Bondar and A. Poluektov, *Eur. Phys. J. C* **47**, 347 (2006); A. Bondar and A. Poluektov, *Eur. Phys. J. C* **55**, 51 (2008).
[15] CLEO Collaboration (Y. Kubota *et al.*), *Nucl. Instrum. Methods Phys. Res., Sect. A* **320**, 66 (1992); D. Peterson *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **478**, 142 (2002); M. Artuso *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **554**, 147 (2005).
[16] *BABAR* Collaboration (B. Aubert *et al.*), *Phys. Rev. D* **78**, 034023 (2008).
[17] Particle Data Group (K. Nakamura *et al.*), *J. Phys. G* **37**, 075021 (2010).
[18] D. Asner, these proceedings.
[19] H. Liu, these proceedings.
[20] LHCb Collaboration, CERN-LHCb-2008-019.
[21] LHCb Collaboration (B. Adeva *et al.*), LHCb-PUB-2009-029.